#2 Sub Spec 8/16/02 amr

TITLE

"OPTICAL TRANSMISSION SYSTEM"

BACKGROUND OF THE INVENTION

The invention relates to an optical transmission system comprising a fixed number of optical fiber line sections of virtually the same length with each section including an optical fiber and a dispersion compensation unit.

Owing to the chromatic dispersion occurring during the transmission of optical signals over optical fibers, and to the self-phase modulation (SPM), distortions are caused in the optical data signal to be transmitted in the case of all optical transmission systems with high data throughput rates, and also in the case of transmission systems operating using the WDM (Wavelength-Division Multiplexing) principle. In this regard, please see Grau and Freude: "Optische Nachrichtentechnik - Eine Einführung" ["Optical communications - an introduction"], Springer-Verlag, 3rd Edition, 1991, pages 120-126.

Such distortions in the optical data signal to be transmitted are functions, inter alia, of the input power of the optical data signal. Moreover, such distortions determine the regeneration-free transmission range of an optical transmission system, that is to say the optical transmission link over which an optical data signal can be transmitted without the need to carry out a regeneration or "3R generation" (electronic data regeneration with regard to the amplitude, edge and the clock pulse of an optically transmitted, digital data signal or data stream).

In order to compensate such distortions in the optical data signal, a provision is made for suitable dispersion compensation units during the transmission of optical signals via optical standard monomode fibers, or use is made of a dispersion management adapted to the optical transmission link. For this purpose, such optical transmission systems are subdivided chiefly into a plurality of optical fiber line sections in which the fiber dispersion respectively caused in the optical fiber line section is completely or partially compensated with the aid of a dispersion compensation unit.

Such dispersion compensation units are configured, for example, as optical special fibers in the case of which the dispersion or fiber dispersion assumes very high negative values particularly in the 1550 nm window owing to a special selection of the refractive index profile in the fiber core and the surrounding cladding layers of the optical fiber. The dispersion contributions generated by the optical transmission fibers can be effectively compensated with the aid of the high negative dispersion values caused by the dispersion-compensating fiber. In addition, the maximum number of optical fiber line sections or the regeneration-free range of the optical transmission system is determined by the eye diagram (eye-opening) of the optical data signal present at the output of the respective optical fiber line section. This results in a maximum range for a regeneration-free transmission of an optical data signal, which is determined in addition by the optical signal-to-noise ratio of the transmission medium.

In optical transmission systems implemented to date, various dispersion management concepts are pursued for this purpose, the optimum dispersion compensation of an optical transmission link being carried out by using pre- and/or

post-compensated optical fiber line sections or differently over- or under-compensated ones. It is therefore possible to transmit over a specific distance without regeneration depending on the fiber dispersion.

It is known in this regard from DER FERMELDE-INGENIEUR: "Wellenlängenmultiplextechnik in zukünftigen photonischen Netzen" ["Wavelength division multiplex technology in future photonic networks"], A. Ehrhardt et al., 53rd Volume, Issues 5 and 6, May/June 1999, pages 18-24 that the system optimum for dispersion compensation of an optical transmission system can be reached for a dispersion compensation of less than 100%. It also emerges from the above-named printed publication that the chromatic fiber dispersion can be compensated to a specific proportion by fiber nonlinearities themselves.

Also known from the publication "320-Gb/s (32*10 Gb/s WDM) Transmission Over 500 km of Conventional Single-Mode Fiber with 125-km Amplifier Spacing" by Bigo et al., IEEE Photonics Technology Letters, Vol. 10, No. 7, July 1998 is an optical transmission system that comprises a plurality of optical fiber line sections of virtually the same length with in each case an optical fiber (SMF) and a dispersion compensating fiber (DCF). In order to increase the transmission range of 32 optical 10 Gb/s signals, a specific dispersion overcompensation is carried out at the start of the optical transmission link, and in each case a dispersion overcompensation is carried out at the end in each case of an optical fiber line section with the aid of dispersion compensating fibers.

SUMMARY OF THE INVENTION

The object of the present invention is thus to configure an optical transmission system of the type mentioned at the beginning in such a way that the dispersion compensation is improved and/or the transmission range reduced by the signal distortions and capable of being bridged without regeneration is increased.

According to the invention, the object is achieved by means of an optical transmission system having a fixed number of optical fiber line sections of virtually the same length with each section having an optical fiber and a dispersion compensation unit with the dispersion compensation units having virtually the same compensation values, which are determined starting from a calculated or estimated accumulated residual dispersion for the at least virtually uniformly distributed undercompensation of the fiber dispersion of the fixed number of optical fiber line sections. By comparison with previous systems with full compensation, the virtually uniformly distributed under compensation according to the invention over the individual optical fiber line sections advantageously permits a virtual doubling of the transmission range that can be bridged without regeneration, that is to say under compensation is performed in the respective fiber line sections to such an extent that the remaining residual dispersion corresponds to a multiple of the absolute-magnitude dispersion according to the invention, and that the residual dispersion along the optical transmission link increases per fiber line section by the absolute-magnitude dispersion in each case.

According to a further refinement of the invention, the optical transmission system has an accumulated residual dispersion that is caused by fiber nonlinearities and the fiber dispersion and decreases virtually linearly with increasing data rate. The

non linear effect of self-phase modulation and the group velocity dispersion (GVD) are the cause of the accumulated residual dispersion at the end of the last fiber line section of the optical transmission link. In the case of fully compensated fiber line sections, they are virtually independent of the input power of the optical data signal, and influence one another mutually, that is to say the self-phase modulation can have a dispersion-compensating effect. Moreover, the group velocity dispersion in the optical fibers increases with increasing data rate, while the self-phase modulation remains virtually unchanged. Consequently, the self-phase modulation (SPM) in the optical transmission system contributes to the dispersion compensation with the dispersion compensating effect of the self-phase modulation (SPM) becoming less with increasing data rate with regard to the group velocity dispersion, that is to say the accumulated residual dispersion decreases with increasing data rate.

In accordance with a further refinement of the invention, the dispersion compensation units are provided for compensating the fiber dispersion of all the optical fiber line sections. The maximum transmission range that can be bridged without regeneration can be implemented, if the residual dispersion advantageously increases in each case virtually uniformly by the same dispersion contribution in all the fiber line sections of the optical transmission system.

All the optical fiber line sections are the optical transmission are advantageously of virtually the same length, the optical fibers of the fiber line section additionally having a minimum length of 20 km. In the case of a minimum length of approximately 20 kilo meters, the signal distortions caused by the fiber dispersion and the fiber non linearities are virtually at their maximum value. Owing to the splitting of the optical transmission system to optical fiber line sections of virtually

the same length and whose number is determined by the optical transmission link to be bridged without regeneration and by the accumulated residual dispersion, an optical transmission system that is optimized with regard to the dispersion compensation and the transmission range that can be bridged without regeneration can be implemented by means of a simple modular design. In particular, the optical transmission system can especially advantageously be implemented a bidirectional data transmission over the fiber line sections owing to the symmetrical design being produced.

Advantageous developments and refinements of the optical transmission system according to the invention are described in the further patent claims.

The invention is to be explained in more detail below with the aid of a block diagram and two graphs.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the principle design of an optical transmission system,

Figure 2 shows a graph of the dispersion management scheme according to the invention, and

Figure 3 shows, in a further graph, the number of the compensated fiber spans or fiber line sections that can be bridged without regeneration, as a function of the distribution of under- or over-compensation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a schematic of an optical transmission system OTS that has an optical transmitter TU and an optical receiver RU. The optical transmitter TU is connected via N optical fiber line sections FDS_1 to FDS_N, each having an input I and an output E, to the optical receiver RU, which in each case have an optical amplifier EDFA, an optical fiber SSMF and an optical dispersion compensation unit DCU.

A first and Nth optical fiber line section FDS_1, FDS_N are illustrated in Figure 1 by way of example, a second to N-1th fiber line section FDS_2 to FDS_{N-1} being indicated with the aid of a dotted line. Moreover, the first optical fiber line section FDS_1 comprises a first optical amplifier $EDFA_1$, a first optical fiber $SSMF_1$, for example an optical standard single mode fiber, and a first optical dispersion compensation unit DCU_1, it being possible also to provide an optical preamplifier - not illustrated in Figure 1 - between the first optical fiber $SSMF_1$ and the first optical dispersion compensation unit DCU_1. Similarly, the Nth optical fiber line section FDS_N has an Nth optical amplifier $EFDA_N$, an Nth optical fiber $SSMF_N$ and an Nth optical dispersion compensation unit DCU_N. In a similar way, it is also possible here to provide a further optical preamplifier - not illustrated in Figure 1 - between the Nth optical fiber $SSMF_N$ and the Nth optical dispersion compensation unit DCU_N.

The optical data signal of the optical data stream OS is transferred by the optical transmitter TU to the input I of the first optical fiber line section FDS_1. Inside the first optical fiber line section FDS_1, the optical data signal OS is amplified with the aid of the first optical amplifier $EDFA_1$ and transmitted to the first dispersion compensation unit DCU_1 via the first optical fiber $SSMF_1$. The signal distortions in the optical data signal OS caused by the optical transmission over the first optical

fiber $SSMF_1$ are compensated in the first dispersion compensation unit DCU_1 except for a first residual dispersion D_{rest1}, which corresponds to the absolute-magnitude dispersion ΔD according to the invention in the case of the first dispersion compensation unit DCU_1. The fixed residual dispersion D_{rest} is a fraction, fixed by the number N of the optical fiber line sections FDS, of the accumulated residual dispersion D_{akk}, which rises virtually uniformly with each compensated fiber line section FDS by virtually the same absolute-magnitude dispersion ΔD.

The accumulated residual dispersion D_{akk} is caused by the fiber nonlinearities and the fiber dispersion, and is present at the end of the Nth fiber line section FDS_N. Moreover, the accumulated residual dispersion D_{akk} is not compensated at the end of the Nth fiber line section FDS_N because of the parameters, required for recovering the data from the optical data signal OS, for the eye diagram or "eye opening". The optical data signal OS present at the output E of the first optical fiber line section FDS_1 is therefore not completely compensated for dispersion, but undercompensated.

In a similar way to this, the optical data signal OS is transmitted over the further optical fiber line sections FDS to the input I of the Nth optical fiber line section FDS_N. The optical data signal OS present at the input I of the Nth optical fiber line section FDS_N is amplified with the aid of the Nth optical amplifier $EDFA_N$, and transferred to the Nth dispersion compensation unit DCU_N via the Nth optical fiber $SSMF_N$. The fiber dispersion, caused by the Nth optical fiber $SSMF_N$, of the optical data signal OS is partially compensated in the Nth dispersion compensation unit DCU_N, from which it can be detected that the residual dispersion D_{rest} of the optical data signal OS rises virtually uniformly by the prescribed absolute-magnitude

dispersion ΔD, and corresponds to the accumulated residual dispersion D_{akk} after the Nth dispersion compensation. The optical data signal OS present at the output E of the Nth optical fiber line section FDS_N is transmitted to the optical receiver RU and, if appropriate, subjected to 3R regeneration - not illustrated in Figure 1 - before further processing.

A dispersion management scheme DCS according to the invention is illustrated schematically by way of example with the aid of a diagram in Figure 2. It is clear therefrom that the optical transmission system OTS is composed according to the invention of a plurality of optical fiber line sections FDS that in each case have an optical fiber SSMF and a dispersion compensation unit DCF, for example a dispersion compensating fiber. In order to explain the dispersion management scheme DCS according to the invention, the number of the optical fiber line sections is limited to four (N=4), such that a first, second, third and fourth optical fiber line section FDS_1, FDS_2, FDS_3, FDS_4 are illustrated in Figure 2, the first optical fiber line section FDS_1 having a first optical fiber $SSMF_1$ and a first optical dispersion compensation unit DCF_1, the second optical fiber line section FDS_2 having a second optical fiber $SSMF_2$ and a second optical dispersion compensation unit DCF_2, the third optical fiber line section FDS_3 having a third optical fiber $SSMF_3$ and a third optical dispersion compensation unit DCF_3, and the fourth optical fiber line section FDS_4 having a fourth optical fiber $SSMF_4$ and a fourth optical dispersion compensation unit DCF_4. As an example, for the dispersion management scheme DCS of the exemplary embodiment the choice here is a virtually identical length for the first to fourth optical fibers $SSMF_1$ to SSMF4 as well as for the first to fourth dispersion compensating fibers DCF_1 to DCF_4.

The diagram has a horizontal axis (abscissa) x and a vertical axis (ordinate) d, the horizontal axis illustrating the distance x from the optical transmitter TU or the range of the optical data transmission, and the vertical axis d illustrating the fiber dispersion d in the respective optical fiber SSMF or in the dispersion compensating fiber DCF.

It is clear from Figure 2 that the fiber dispersion of an optical data signal OS present at the input I of the first optical fiber line section FDS_1 rises linearly from the optical transmitter TU (x=0) along the first optical fiber $SSMF_1$ and assumes a first maximum absolute-magnitude dispersion D_{max1} at an end x_1 of the first optical fiber. The first maximum absolute-magnitude dispersion D_{max1} is partially compensated with the aid of the first dispersion compensation unit DCF_1 or the first dispersion compensating fiber, that is to say at an end x_2 of the first dispersion compensating fiber there is present a first residual dispersion D_{rest1} that corresponds at the output E of the first dispersion compensation unit DCF_1 to the absolute-magnitude dispersion ΔD.

Owing to the following second optical fiber $SSMF_2$, the fiber dispersion d increases from the first residual dispersion D_{rest1} up to a second maximum absolute-magnitude dispersion D_{max2} that is present at an end x_3 of the second dispersion compensating fiber. The second maximum absolute-magnitude dispersion D_{max2} is compensated with the aid of the second dispersion compensation unit DCF_2 or the second dispersion compensating fiber until the second residual dispersion D_{rest2} corresponds to twice the absolute-magnitude dispersion ΔD, that is to say the remaining residual dispersion D_{rest} rises uniformly per optical fiber line section FDS by the absolute-magnitude dispersion ΔD in each case. Consequently, at an end x_4 of

the second dispersion compensating fiber, a second residual dispersion D_{rest2} is present which corresponds at the output E of the second dispersion compensation unit or the second dispersion compensating fiber DCF_2 to twice the absolute-magnitude dispersion ΔD.

The optical data signal OS transferred by the second dispersion compensating fiber DCF_2 to the third optical fiber $SSMF_3$ in turn experiences in the third optical fiber $SSMF_3$ signal distortions caused by the fiber dispersion d which assume a third maximum absolute-magnitude dispersion D_{max3} at an end x_5 of the third optical fiber. The third absolute-magnitude dispersion D_{max3} is undercompensated by the third optical dispersion compensation unit DCF_3 in such a way that the remaining third residual dispersion D_{rest3} corresponds to three times the absolute-magnitude dispersion ΔD according to the invention, that is to say at an end x_6 of the third dispersion compensating fiber the residual dispersion D_{rest} assumes a third residual dispersion D_{rest3}, which has increased once more by the absolute-magnitude dispersion ΔD by comparison with the second residual dispersion D_{rest2}.

Furthermore, the optical data signal OS present at the output E of the third dispersion compensating fiber DCF_3 is transferred to the fourth and last optical fiber $SSMF_4$ of the optical transmission system OTS. It becomes clear with the aid of Figure 2 that the fiber dispersion d continues to increase, and has a fourth maximum absolute-magnitude dispersion D_{max4} at an end x_7 of the fourth optical fiber. With the aid of the fourth dispersion compensation unit DCF_4, the fourth maximum absolute-magnitude dispersion D_{max4} is reduced to the absolute magnitude of the accumulated residual dispersion D_{akk}, which corresponds to four times the absolute-magnitude dispersion ΔD according to the invention. The remaining residual dispersion D_{rest} of

the optical transmission system OTS thereby has the absolute magnitude of the accumulated residual dispersion D_{akk} at an end x_8 of the optical transmission link or at the end of the fourth fiber line section.

The transmission range x_8 that can be bridged without regeneration is virtually doubled by the uniform "splitting up" according to the invention of the accumulated residual dispersion D_{akk} calculated or estimated for the respective optical transmission system OTS into a fixed number of fiber line sections FDS. Here, the fiber line sections FDS of the optical transmission system are undercompensated as a function of the length of the respective optical fiber SSMF as far in each case as a residual dispersion D_{rest} fixed by the accumulated residual dispersion D_{akk}, the residual dispersion D rising from fiber line section FDS_1 to fiber line section FDS_2 by the same absolute-magnitude dispersion in each case.

By comparison with a dispersion management scheme DCS that fully compensates the respective fiber line section FDS of an optical transmission system OTS, the dispersion management scheme DCS of the distributed undercompensation according to the invention can substantially increase the range that can be bridged without regeneration, which leads to a saving of cost-intensive electric 3R regeneration devices.

Moreover, it is possible to implement a bidirectional data transmission over the fiber line sections FDS considered in a simple way on the basis of the symmetrical design, to be seen in Figure 2, of the optical transmission system OTS.

In addition, a fiber line section FDS having an optical fiber SSMF and a dispersion compensation unit DCF can be configured as an optical transmission module M. Consequently, the optical transmission system OTS can be formed by a series circuit of such optical transmission modules M. Such a modular design substantially facilitates in practice the implementation of an optical transmission link or the extension of an existing optical transmission link.

Furthermore, the use of the distributed undercompensation according to the invention is particularly advantageous in the case of optical transmission systems that, because of the data transmission with the aid of a plurality of transmission channels, have a strong cross-phase modulation (XPM) as regards the effect limiting the transmission ranges that can be bridged without regeneration. This strong cross-phase modulation (XPM) can be suppressed by means of the provision according to the invention of a slight, local residual dispersion D_{rest} at the end of a fiber line section FDS. Consequently, not only is the self-phase modulation (SPM) suppressed by the distributed undercompensation according to the invention, but the influence of the cross-phase modulation (XPM) is substantially reduced virtually simultaneously.

The number of the compensated fiber line sections nfs that can be bridged without regeneration is illustrated in a further diagram in Figure 3 as a function of the distributed under- or overcompensation uoc for different input powers P4dBm, P6dBm, P9dBm, P12dBm, P15dBm of the optical data signal OS.

The further diagram has a horizontal axis (abscissa) uoc and a vertical axis (ordinate) nfs, the horizontal axis uoc illustrating the "under- or overcompensation"

scheme, provided for the dispersion compensation, of the optical transmission system OTS, and the vertical axis nfs illustrating the number of the compensated fiber spans or fiber line sections FDS of the optical transmission system OTS. It may also be seen that the uniform undercompensation according to the invention of the plurality of fiber line sections FDS permits an increase in the transmission range that can be bridged without regeneration. The transmission range that can be bridged without regeneration is illustrated in the further diagram by the number of the compensated fiber line sections FDS of the optical transmission system OTS.

For this purpose, a first to fifth optical data signal OS1 to OS5 is fed to an optical test transmission system OTS that has a different input power P in each case. Here, the first optical data signal OS1 has an input power of 4dBm, the second optical data signal OS2 an input power of 6dBm, the third optical data signal OS3 an input power of 9dBm, the fourth optical data signal OS4 an input power of 12dBm, and the fifth optical data signal OS5 an input power of 15dBm.

The increase in the transmission range that can be bridged without regeneration is particularly clear on the profile of the curve for the first optical data signal OS1, since the first optical data signal OS1 can be transmitted without regeneration over virtually 120 fiber line sections FDS in the case of an undercompensation of approximately 0.5 km of a standard monomode fiber (SSMF). In this case, the respective fiber line section FDS is respectively compensated by the dispersion compensating fiber DCF to such an extent that a residual dispersion D_{rest} is present that corresponds to an uncompensated optical fiber length of half a kilometer (0.5 km).

WE CLAIM: